Success Factors for Mathematical e-Learning Exercises Focusing First-Year Students

Malte Neugebauer[a], Basile Tousside[b] and Jörg Frochte[c]
Bochum University of Applied Sciences, 42579 Heiligenhaus, Germany

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Abstract: How university students succeed in math courses at the beginning of their studies is of great relevance for the overall study success in many study programs. Since the competence levels of candidates are different, lecturers struggle to mediate knowledge to such heterogeneous audiences simultaneously. In tacit consent, a catch-up of lower-skilled students is expected. Self-organized learning materials – which are often accessible via e-learning – are mostly unattractive, especially to lower-skilled students. Since gamification is successfully used in other areas of education to support motivation and performance, we propose gamification as a first success factor for mathematical exercises. Considering infrastructural aspects of higher education, we furthermore suggest the gamification systems' ability to be extended by lecturers, its integrability into universities learning management systems and its affordability as success factors for mathematical e-learning exercises. Therefore, we implemented an open-source and easy-to-extend software approach, which is integrable into universities' learning management systems. In an initial test run among first-year students ($n = 115$), we show how this approach improves learning and motivation at the same time. We discuss these results and propose this approach for testing in multiple group plans, to further investigate the influence of single game elements on motivation and learning.

1 INTRODUCTION

During the last decade, e-learning in mathematics grew in relevance for higher education institutions. Not only was the COVID-19 pandemic, which forced universities into switching entirely to distance learning during 2020, of great relevance for mathematical e-learning (Lisnani et al., 2020; Irfan et al., 2020), but also the broader diversity of students – regarding life scripts and competence levels – boosted the importance of self-paced e-learning materials (Liang et al., 2018; Schulmeister, 2004). Especially introductory courses are challenged to offer learning materials to their students that fit learners' different competence levels (Gordon et al., 2013). Here, self-paced learning with e-learning materials enables students to revisit knowledge from school, helping lower-skilled students catching up.

However, Büchele and Marten (2022) found that students with low math competencies fall back even more during their studies due to a low motivation towards self-regulated mathematical learning. Despite the fact that math is of great relevance for the success of many study programs, students have a smaller motivation towards it. This can possibly be traced back to a given distance of the chosen study program (e. g. psychology, architecture or computer science) to mathematics.

One promising method to raise motivation in different subjects is gamification, which is known as "the use of game design elements in non-game contexts" (Deterding et al., 2011). Especially in higher education it is widely used to raise students' motivation, reduce drop-out rates or support learners' performance (Zainuddin et al., 2020a; Dichev and Dicheva, 2017).

Despite the fact, that most studies about gamification take place in higher education (Dicheva et al., 2015), studies focusing on the specific case of mathematics in this context are rare. Surprisingly, math-related gamification research is more common in the context of elementary and secondary school. One possible reason is the size of the target group. The number of students of the university entrance phase, especially if one splits them up by subjects, is consid-

[a] https://orcid.org/0000-0002-1565-8222
[b] https://orcid.org/0000-0002-9332-5060
[c] https://orcid.org/0000-0002-5908-5649

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erably smaller than within a school year. Commercial solutions are economically less attractive in this context or would have to be managed with smaller budgets. Affordability appears to be a facilitating factor.

Since many universities are using learning management systems (LMS) to facilitate self-paced and distance learning for their students, an LMS-based gamification of mathematical e-learning content could be a useful alternative to commercial solutions. Integrability into universities' LMS will allow a gamification solution to make use of an already established platform and, in this, support existing tools like question banks or learning analytics systems. By using external gamification tools – even on equipping them with an interface for data exchange to LMS – more data protection law issues may arise compared to an in-house, LMS-integrated solution.

An additional, more socio-scientific phenomenon is the raising heterogeneity of students. This leads to a diversification of students' needs depending on their age, social background and family responsibilities. Here, a highly extendable software solution is needed, to address a constantly changing target group.

Considering (i) gamification, (ii) affordability, (iii) extendibility and (iv) integrability of the software into university LMS platforms as success factors for mathematical exercises in e-learning, here we develop a software architecture for LMS, that allows lightweight implementation of gamification into exercises to support mathematical learning in the early phase of higher education. In a first test run we show, that this easy-to-implement approach is capable not only of raising motivation, but also helps new students revisiting their math knowledge, concluding to a score progression during exercise accomplishment.

Our contributions are summarized as follows:

- We present a frontend-oriented software architecture, that allows lightweight gamification implementations into universities LMS without any server-sided changes.
- Focusing on mathematical e-learning, we develop a gamification exercise design based on the frontend-oriented approach and demonstrate a possible implementation inside the LMS Moodle.
- We analyze the results of a first test run with the given approach and show, how learners are motivated to solve the most challenging exercises and progress in their score performance.
- We discuss how specific game elements influence learners' motivation and learning outcomes.
- We propose to test this approach in multiple group plans to shed more light on the effect of specific gamification elements for specific learner groups.

2 RELATED WORK REGARDING GAMIFICATION

Since its first mention in the early 2000s (see Khaitova (2021) for genesis), gamification became a widely spread phenomenon in various areas, such as marketing (Hofacker et al., 2016) or onboarding (Fischer and Heinz, 2020). There are many studies showing the effectiveness of gamification in higher education in various ways, using a variety of different game design elements, ranging from points, badges and leaderboards over competitions to virtual goods, all accompanied with evident effects (Dicheva et al., 2015).

Although gamification research mostly takes place in higher education (Dicheva et al., 2015), studies regarding mathematics mostly focus on primary or secondary school. Mathematics-related gamification studies, that take place in higher education usually investigate students' feedback to quiz software solutions like *Kahoot!*, *Socrative* or *Quizizz* or (Zabala-Vargas et al., 2021; Zainuddin et al., 2020b; Bullon et al., 2018). Those software solutions do not fit all the success factors mentioned above since they are commercial (affordability) and they are only integrable into LMS by embedding or sharing them via an external link (integrability). In contrast to this, we take the special needs of higher education into account to offer an affordable, easily integrable and extendable gamification solution.

The few studies focusing on gamification of mathematical learning in the specific context of the transition phase between school and university barely address their technical implementations. Gordon et al. (2013) for example present results of an approach using different game elements, paying special attention to the possibility of repeating attempts (which is further referred to as the *freedom to fail* gamification design principle). But the technical aspect of how the game elements were implemented into the exercises is not thematized, making this approach hardly reproducible. In contrast to this, we propose an open-source solution for web-based LMS, which explicitly aims at being able to be adapted to the specific needs of local students through its extendibility.

3 DERIVING GAMIFICATION DESIGN PRINCIPLES FOR MATHEMATICAL E-LEARNING

For deriving appropriate game elements, we make use of findings from behavioral economics and from psychology of learning. In the context of gamification, the self-determination-theory (SDT) (Ryan and Deci, 2000) is often referenced to explain raising intrinsic and extrinsic motivation through gamification (Zainuddin et al., 2020a). As per this theory, a raise of intrinsic motivation appears, when three basic needs are satisfied: competence, autonomy and relatedness. Game elements bear the potential to tackle these needs (van Roy and Zaman, 2017).

Besides motivation, our approach aims at facilitating students' learning process. The Fogg Behavior Model (FBM) (Fogg, 2009) considers both motivation and ability at the same time to explain behavioral change. As per the FBM, behavior is seen as a convergence of motivation, ability and a prompt. When both, motivation and ability merge to a sufficient degree, a prompt succeeds. Even if a hard task is prompted, people will follow the prompt when the motivation is high enough. For our use case, a rise in motivation through gamification is expected. But for our aim to facilitate learning in higher education mathematics, solely raising motivation is not sufficient. Additionally, we aim to raise the needed math-competence, so that previously too difficult tasks become solvable. Both, raising motivation towards exercise accomplishment and enabling learners to solve challenging exercises complement each other when behavioral change is desired.

As per Vygotsky's model of proximal development (Vygotsky, 1978; Podolskiy, 2012), learning takes place when people go beyond their comfort zone. In the so-called growth zone, challenging tasks are accomplished and finally assimilated into the comfort zone. Tutoring and repetition are facilitators for this process. Since math is highly modular (Avigad, 2018), math exercises can be built upon each other, so that learners can learn new things by deploying established knowledge on new challenges. In this, their comfort zone increases exercise by exercise. Or speaking with the FBM: They are more and more enabled to accomplish challenging tasks, reducing the barrier of following the next prompt – which is the next exercise.

To realize learning this way with the help of e-learning exercises, learners have to be supplied with additional material to understand those exercises, that go beyond their comfort zone. Furthermore, feedback on their current performance in general and on specific mistakes will support the assimilation of challenging tasks into their comfort zone. Here we use the design principles of gamification to increase motivation on the one hand and to enable learning progress on the other. State-of-the-art gamification research demands elucidating the effects of single game elements instead of giving a proof-of-concept for an overall gamification approach (Behl et al., 2022; Zainuddin et al., 2020a). Following this demand, we base our reflections about game elements on a taxonomy which is derived from a systematic mapping study for the context of education (Dicheva et al., 2015). This taxonomy is already well-referenced (Ayastuy et al., 2021; Jueru et al., 2019; Piteira et al., 2018).

Out of the 15 so-called *gamification design principles* from this taxonomy, it is reasonable to assume that, based on the theoretical reflections above, the following four principles will raise motivation and support learning in a mathematical exercise e-learning design.

1. *Immediate Feedback*: This principle will supply learners with the needed information to solve exercises correctly, after failing them before. Regarding the SDT, in this the need of competence is tackled.
2. *Freedom to Fail*: Since repetition is an important facilitator of learning, learners have to be enabled to repeat exercises without penalty. This allows them to immediately apply the given feedback and prove acquired knowledge – if any – to themselves and to lecturers. The need for autonomy is tackled here.
3. *Freedom of Choice*: Enabling learners to freely move between easier and harder tasks will allow them to identify gaps on their own and acquire the needed knowledge. Regarding the SDT, here again autonomy is enabled and a raise of motivation is expected.
4. *Goals*: Regarding the FBM, exercises fill the role of the prompt. This prompt can be emphasized by declaring motivating goals towards exercise accomplishment, boosting learners' motivation.

From this, we derive an exercise design in which learners have the opportunity to repeat exercises without penalty and move freely back and forth through the exercises. Furthermore, after accomplishing an exercise, a sample solution and – where applicable – additional specific feedback regarding the mistake is given. On repeating exercises, another variant of the exercise is presented (randomization) to enable learning (instead of typewriting the sample solution). Finally, the exercises are structured by topics and presented in raising difficulty. Solving the last (thus hardest) exercises is declared as the goal of this design. To emphasize this goal, we use game-like wording by calling the hardest exercises *boss* questions – marked by a skull – and the topics *math worlds*.

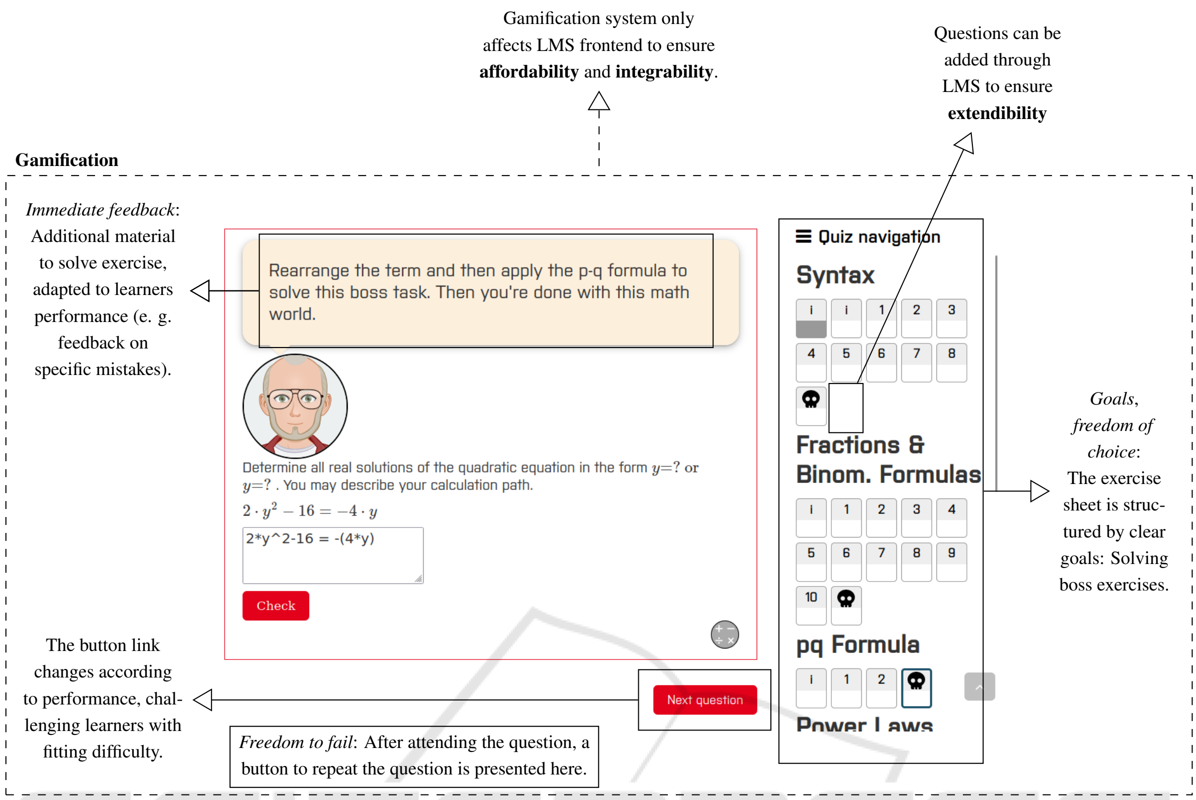

Figure 1: Adaptations of a mathematical exercise inside the LMS Moodle, serving the four success factors (bold). In italics: The chosen gamification design principles.

Figure 1 gives an insight into the appearance inside the LMS Moodle.

4 PROPOSED SOFTWARE SOLUTION AND IMPLEMENTATION

After comparing different gamification software architectures, we introduce a frontend-oriented architecture, to satisfy integrability and extendibility. This will be presented in section 4.1. In comparison to a plugin, this solution doesn't require any server-sided changes. An example implementation inside the LMS Moodle will be presented in section 4.2. Finally, the technical limitations of this approach will be addressed in section 4.3.

4.1 Gamification Software Architecture Requirements

To ensure the affordability, integrability and extendibility of a gamification implementation in higher education, different gamification software architectures (GSA) can be considered. Herzig et al. (2014) cluster GSA into four different classes: achievement systems (AS), generic gamification platforms (GGP), integrated solutions (IG) and others. Assuming, that extendibility can be understood as a combination of flexibility, manageability and reusability, comparing properties of GSA (see Table 1), the GGP achieves the best results regarding flexibility, manageability, reusability, and integrability. Nevertheless, this class is still evaluated as low in performance, highly complex and only a medium degree regarding integrability.

Table 1: Comparison of classes (↑: high, →: medium, ↓: low, ○: not considered) (Herzig et al., 2014).

Degree of	AS	GGP	IG
Flexibility	→	↑	↓
Invasivity	→	↓	↑
Reusability	→	↑	↓
Integrability	↓	→	○
Performance	→	↓	↑
Analyzability	→	↑	↑
Manageability	→	↑	↓
Complexity	↓	↑	↓

Most higher education institutions are using an LMS as an information system for their students. It can be used to overcome the just mentioned disadvantages of the GGP. In case of the web-based LMS Moodle, with the help of the programming language JavaScript, a gamification platform can be implemented right into its frontend (Figure 2). This will lead to a rise in integrability and performance, while reducing the complexity, satisfying the demand for extendibility and integrability.

To tackle affordability, we give an implementation proposal for the LMS Moodle and publish it under an open-source license.

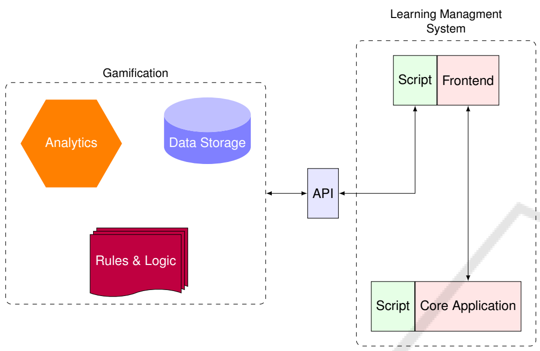

Figure 2: The suggested frontend-oriented software architecture.

This frontend-oriented architecture has the additional benefit that gamification can be implemented without any security risks and without involving the institution's IT department, which could be an additional obstacle in higher education institutions' infrastructure. In contrast to a plugin for example, this solution can directly be implemented by question authors.

4.2 Moodle Example Implementation

To demonstrate a practical implementation, we show below how the chosen gamification design principles can be implemented with the help of a frontend-oriented approach in the LMS Moodle. One reason for choosing Moodle is that it is used by many local partners, which facilitates testing the adaptability in different universities. Furthermore, adaptations to Moodle – e. g. with the web-programming language JavaScript – can be easily transferred into other web-based LMS (Blackboard, D2L, Canvas, ILIAS, ...).

To apply the gamification system inside the frontend of a mathematical exercise in Moodle, as shown in Figure 2, at first, a question element has to be created and then the script has to be included inside the question text as illustrated below:

```
<script src="alquiz.js></script>
<script>
ALQuiz.setCurrentQuestionId("questionId");
</script>
```

where `alquiz.js` and `questionId` are respectively the path to the script offered in the repository presented and the identifier of the question declared in the last quiz element as described below. Furthermore, the code line

```
<script>ALQuiz.incrementSolved();</script>
```

has to be added to the feedback text, which is shown on success. This will inform the gamification system that the user solved a question correctly.

Unless the question does not stand for itself but is part of a series of exercises – in Moodle realized by the quiz element – authors can structure questions with the help of the proposed gamification system by *levels* and *worlds*. In this, the *goals* principle is emphasized. To do this, in the last element of the quiz, the questions have to be declared by a given syntax, e. g.:

```
...
},
{
    id:"fra_a",
    needs:1,
    onsuccess:"fra_b",
    onfailure:"fra_instructions"
},
{
    id:"fra_b",
    needs:1,
    onsuccess:"fra_c",
    onfailure:"fra_a"
},
{ ...
```

In this example, two questions are declared identified by `fra_a` and `fra_b` (giving question authors the hint that it is about the first and second question of the *fractions world*). Solving the first question will lead the user to the question identified by `fra_b` (`onsuccess` attribute), while failing will lead them to the instructions page of this *math world* (`onfailure` attribute). To discern failure from success, the script needs to know, how many times the function `ALQuiz.incrementSolved()` has to be called to validate an exercise as completely solved. This is represented by the `needs` attribute.

Furthermore, we made use of the STACK question type. This question type enables authors to test users' input against specific error patterns to give specific feedback. The authored feedback then is presented automatically to those learners that run into specific error patterns. The additional JavaScript moves the feedback into the speech bubble of the supportive figure.

Figure 1 demonstrates how the frontend of a Moodle exercise is adapted to implement the chosen gamification design principles and serve the given success factors. Enabling moving freely through exercises and being able to repeat exercises without penalty after failing has to be configured by the quiz settings in the backend of the Moodle course. See the repository for further instructions and explanations.

4.3 Technical Limitations

Besides the advantages of a frontend-oriented software architecture – gamification through an affordable, integrable and extendable approach – coping without server communication is also accompanied by limitations.

Social interaction is a well-used element in gamification approaches. For example, automatically presenting points or badges from other players or ranking all participating local learners are known as additional motivators (Majuri et al., 2018). Communicating information about other players is realized by a server. A frontend-oriented approach is in itself not capable of communicating this information to other players.

Coping without a server also comes along with the impossibility to synchronize data between devices. The frontend-oriented approach stores the data locally by default. When users start an exercise on one device and continue it later on another device, the data of the gamification system is not transferred by default.

Adding an additional server to the architecture would overcome this problem. However, this would also lead to greater effort, which was originally intended to be avoided considering higher education institutions' infrastructure.

Such an additional server may be acting independently of the LMS or can be combined with it. If a social interaction and/or data synchronization between devices is desired, a conventional GSA – AS, GGP or IG – would be more appreciated here, since server communication is an integrated part of each of these solutions (Herzig et al., 2014). But facing, that this would mean to trade-off affordability, extendibility or integrability, the frontend-oriented approach extended with an additional server may be a good choice despite the bigger effort.

Among the derived gamification design principles for mathematical e-learning exercises (section 3), no principle containing social elements was identified as relevant. This would have been applied to the *competition and cooperation* and *visible status* principles. Since neither data synchronization nor social interaction is required in this project, the frontend-oriented approach without any server communication is the tool of choice.

5 EXPERIMENT & RESULTS

The approach presented above – hereafter called *training area* – was tested in two math preparatory courses. The test aimed to get insight into the following questions.

1. How motivated are students to accomplish the training area? We used a standardized questionnaire and found that students perceive themselves as motivated during accomplishment and expect to be motivated to solve training areas like this in the future. We will elaborate more on this in Section 5.2.
2. How do students perceive the use of game elements in this exercise design? In the given questionnaire, we also asked students for their evaluation of the used game elements. It shows up that students overall perceive the usage of game elements as suitable, but mostly appreciate, that exercises appear in ascending difficulty as shown in section 5.3.
3. How do students move through the training area? Here we analyzed students' usage data and found that students retry *boss* questions more often than other questions. This can be interpreted as a raised motivation to solve *boss* questions as described in section 5.4.
4. How does the tutor feedback affect students behavior? Section 5.5 deals with this question. We conducted a deeper analysis of students' tries of the *boss* questions and found that a considerable number of students progressed toward the correct answer.

Furthermore, students were asked about their overall satisfaction with the current course design. This, and asking for their improvement suggestions, aimed to generate ideas for further development of the training area.

5.1 Experiment Design

The test took place at university in two different locations in a given time slot of 90 minutes. Overall 115 participants took part in it. For our use case, the approach consisted of 28 math questions from the topics fractions, binomial formulas, pq formula, power laws and trigonometry. Furthermore, the approach included 9 questions to learn how to enter answers to be correctly interpreted by the underlying computer algebra system (CAS).

After finishing the training area, a standardized questionnaire awaited each user as the last part of the training area. This questionnaire aimed to evaluate the usability of the training area and how motivated students were by the exercise design. It contains 7 scaled evaluation questions, 2 multiple choice questions and 2 free text questions.

In the scaled questions, the participants are asked, to what extent they agree with the given statements shown in Table 2 from 1 (completely disagree) to 5 (completely agree).

Table 2: Questionnaire evaluation questions (EQ).

EQ1	Compared to solving exercises in school, I was more motivated to solve exercises in the just accomplished training area.
EQ2	The provided support helped me with solving the exercises.
EQ3	The ascending difficulty combined with the question design helped me to stay on track.
EQ4	I appreciated that the questions appeared in ascending difficulty.
EQ5	I can well imagine to use training areas like this as accompanying learning tools for my studies.
EQ6	I perceived the use of gamification elements (levels, worlds, bosses) as suitable.
EQ7	I think that illustrating the support by an icon was basically a good idea.

The evaluation questions (EQ) can be divided into three groups.

- EQ1, EQ3 and EQ5 aim to evaluate the perceived motivation to accomplish the training area now or in the future.
- EQ2, EQ4, EQ6, EQ7 aim to get insights into how satisfied students are with the course design and what adaptations would be welcome in the future.

The multiple-choice questions (MCQ) ask for the used device during accomplishment (MCQ1) and where the participants expect to use it in the future (MCQ2). The free text questions (FTQ) are shown in Table 3. The answers to these two questions were analyzed using the qualitative content analysis (Fenzl, 2014).

Table 3: Questionnaire free text questions (FTQ).

FTQ1	What general feedback about the gamification elements (level, worlds, bosses) do you want to provide?
FTQ2	What general feedback regarding the usability of the training area do you want to provide?

To get further insights into how the learners used the training area, the usage data that was automatically logged by the LMS was acquired. In addition to the common data the Moodle web surface offers to course administrators, this enables us to see how often users repeat questions and in what amount users succeeded in a question after failing it before.

Thanks to the STACK question type (see section 4.2) additionally to the default logged data we were able to recapitulate what error patterns users pass through and how the specific feedback helped learners to progress in their score performance.

5.2 Students Perceived Motivation

Figure 3 shows different aspects of students' perceived motivation.

Most users state to be motivated to solve the exercises of the training area during accomplishment compared with solving exercises in school (EQ1).

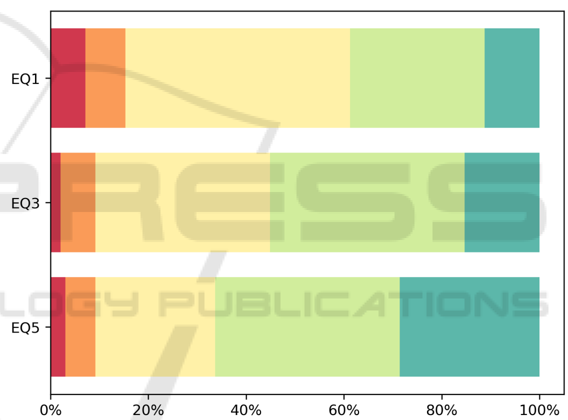

Figure 3: Users evaluation of their motivation towards the training area from total disagreement (red) to total agreement (dark green) in percent.

EQ3 asks for the student's perception, of how the combination of question design and the raising difficulty of questions helped the students to stay on track. Figure 3 shows, that most students affirm, that this is the case.

Even more users say, that they can well imagine, to use training areas like this as accompanying learning tools for their studies (EQ5).

One can overall say, that the use of this training area is accompanied by a basic motivation, to solve exercises like this now and in the future. Unfortunately, there is no comparable data to further prove that. A control- and test-group research design is addressed in section 7 to overcome this weakness of this study.

Apart from that, it is important to consider, that students state to be motivated, although they were unsatisfied with the correct input of math syntax in a large amount.

On analyzing the answers to the free text questions, we found 111 entities encoded as described below (amount of entities in brackets).

1. General positive feedback (49),
2. negative feedback regarding the syntax(-input) (26),
3. general negative feedback (17),
4. negative feedback regarding the input for multiplication (15)
5. feedback regarding solution(-paths) (4).

Hence, negative feedback is predominantly related to the input of math calculations. Especially the necessity of using the * as a multiplication sign, even though a multiplication could be implied by the CAS (like e. g. in $2x$), was noted as “annoying”, “taking away the pleasure in solving the exercises”. For example: users had to write $2*x$ instead of $2x$ for a valid answer. Originally, the question designers intended to make the users familiar with math input in programming languages or CAS, because these are often used during the soon to be starting studies of the participants. Due to the given feedback, it has to be considered anew, whether this approximation to CAS syntax is worth the loss of pleasure during exercise solving.

Although this interferes with the unsatisfactory kind of how math is entered, an overall perceived basic motivation can be derived from the given answers of the students. All the more, that students still stated to be motivated, despite the fact that the input of math was recognized as annoying, can be interpreted as a special benefit of this approach. It has to be assumed, that the perceived motivation is even higher, when the affliction to enter math forumlas in the same way as for a programming language or a CAS is removed.

The motivating aspect of the exercise design is also mirrored in the answers to the free-text questions. For example, users say about the training area:

- “This makes it a little more motivating to solve the exercises.”
- “I think the concept is a great idea and incredibly motivating for learners. It’s notably less boring and jog-trot than conventional learning.”

Apart from asking for the perceived motivation, examining the usage data gives further insight into how learners were motivated to solve the most challenging exercises. This will be described below.

5.3 Students’ Evaluation of Game Elements

As shown in Figure 4, students evaluate the feedback, the ascending difficulty, the game-like structure (*levels*, *worlds*, *bosses*) and the tutor-icon mainly positively.

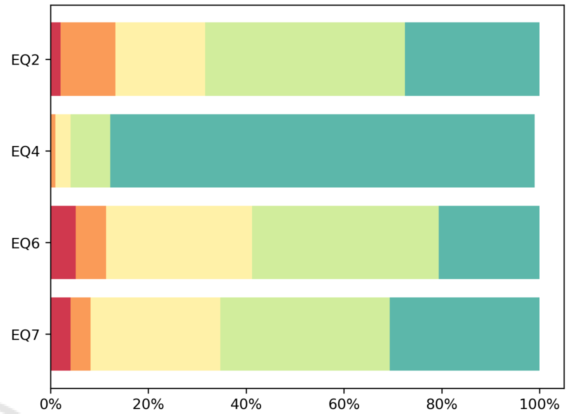

Figure 4: Students’ evaluation of different elements of the game-like interface from total disagreement (red) to total agreement (dark green) in percent: Feedback (EQ2), ascending difficulty (EQ4), game-like structure (EQ6), tutor-icon (EQ7).

The averages of each statement lie above a neutral center. Special attention can be paid to the ascending difficulty (EQ4). Here, 87% of learners totally agree with the statement “I appreciated, that the questions appeared in ascending difficulty.” Obviously, learners enjoyed especially the challenging aspect of the exercise design.

5.4 Students’ Pathway Decisions

In the given approach students were able to move freely through the course as described above with the *freedom of choice* gamification design principle (section 2). By analyzing students’ pathways, we found, that people decide more often to visit and retry *boss* questions compared to other questions. Figure 5 shows in what amount users reattend questions after their first try. The five *boss* questions (red) all have a mean number of retry of at least or equal 0.5, which is significantly higher than for most other questions ($r = 3.43$, $p = 0.0015$, t-test).

To clarify the reason for that, the relation between the mean number of retries to other values was tested with a person’s correlation test. Beforehand, the last but one question was removed from the dataset as an outlier. But neither for question difficulty ($r = 0.059$, $p = 0.752$) nor for number of attempters ($r = -0.137$,

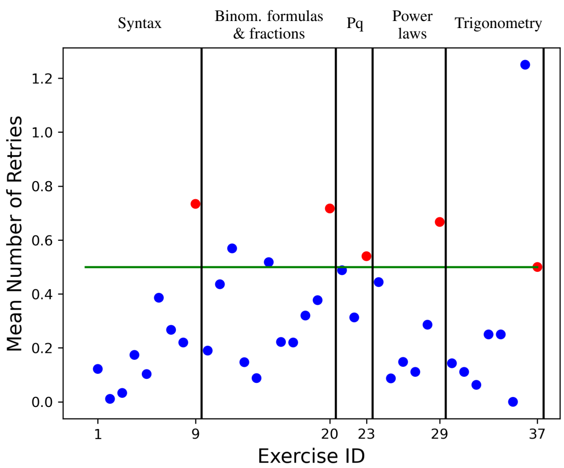

Figure 5: Mean number of retries by questions after first accomplishment, structured in the five *worlds*.

$p = 0.418$) a significant correlation to the mean number of retries of *normal questions* was found.

This makes it presumable, that the raised mean number of retries of *boss* questions traces back to an enhanced motivation of students to solve them in account of the question design. This is supported by some of the free-text answers of the students from the accompanying questionnaire. E. g. students say about the training area:

- "Makes learning more varying and structures it by clear goals (boss)."
- "I only solved the boss questions, because I was looking for the greatest challenge. I liked, that I could directly jump there."

Furthermore, the *boss* questions are a recurring part in the suggestions for improvements. Students suggest:

- "An indicator, that a world is solved after finishing the boss."
- "In the end, you could add a health points bar to the boss."

This makes it assumable, that the given gamification approach – especially the feature related to the game attribute *goals* –, motivates students to confront themselves with the hardest exercises.

5.5 Feedback Effects

Immediate feedback was identified as one important principle in gamification approaches in higher education mathematics preparatory courses (section 2). To analyze the effects of this on students and their motivation, we examined the usage data regarding retries of single questions.

Figure 6 shows for the *boss* task of the syntax *math world* as an example, that at the beginning (0) 34 persons succeeded at the first attempt (C), 28 persons failed (W) and 30 persons were partially correct (P1). If the answer is not correct, a sample solution is shown to the students. If the answer is partially correct, the specific error is described additionally. In the specific example of the syntax *boss* task, the students will be asked to give two possible solutions, if they only gave one. The students are then free to skip the question or to repeat it with different numbers (randomization).

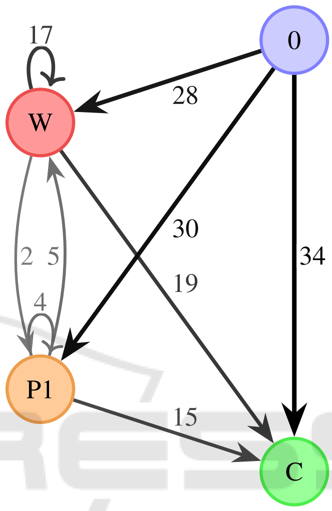

Figure 6: Users progress in the syntax boss question. 0: Starting point, C: Correct, W: Wrong, P1: Partially correct (offered only one solution where two were expected). Annotated arrows represent the amount of movements.

Proceeding from these initial movements, we see here, that students do not only retry questions in a notable amount (as already shown in section 5.4), but that they also progress towards a correct answer. There are for example 19 movements from wrong (W) to correct (C) and 15 movements from partially correct (P) to correct (C).

Table 4: Amount of learners that were initially wrong (W) or partially correct (P) in boss exercises, mapped onto the amount of movements toward a correct answer.

World	W / P	Score-Raise	Ratio
Syntax	58	36	62%
Binom. formulas & fractions	41	23	56%
Pq formula	34	11	32%
Power laws	16	9	56%
Trigonometry	9	1	11%
Sum	158	80	51%

Summing up the movements towards a better score (e. g. 36 movements for the syntax world – movements from wrong to partially correct included) divided by the number of learners, that initially failed or accomplished only partially correct (58 learners), the amount of progression movements can be expressed in relation to the learners (62%). Regarding the *boss* questions, there is an overall progression of 51% (see Table 4).

6 DISCUSSION

Each of the questions regarding learners' perceived motivation is answered positively, on average lying above neutral. One can say, that learners are overall motivated to accomplish exercises designed this way. Surprisingly, this positive result is achieved despite overall displeasure with the way multiplications have to be entered to be validated by the CAS.

The answers to the questions regarding specific elements of the exercise design are also lying above neutral. The majority of students evaluate the feedback-element as helpful. Furthermore, the tutor-icon and the usage of a game-like structure (*levels*, *worlds*, *bosses*) are perceived as suitable. The ascending difficulty of exercises is especially appreciated.

The significantly higher repetition rate of *boss* questions shows, that the high motivation is especially channeled towards these most challenging exercises. Obviously, learners focus on accomplishing these hardest questions, following the prompt derived by the *goals* gamification design principle.

Taking a closer look at the progress learners make in repeating *boss* exercises it shows, that there is an overall progression towards the correct answer, which can be expressed by the relation between the number of learners who don't solve the exercise at first to the number of learners who raise their score in this exercise. Here we measured an overall progression of 51%, meaning, that on average half of the learners that were initially wrong or partially correct in a *boss* exercise raised their score in this exercise by retrying it once, twice or more.

We showed that gamification can be implemented into universities LMS by a frontend-oriented software architecture. Thus, enabling the implementation of an affordable, integrable and extendable gamification solution is possible. Independent from the technical limitations accompanying a such lightweight approach, a raise of motivation and a learning progress can be seen.

Combining the gamification design principles *goals*, *immediate feedback*, *freedom to fail* and *freedom of choice*, the given exercise design leads to a raised motivation, where the highest motivation applies to the *boss* exercises. To solve these is the declared goal of the design (*goals* principle). Unless there is not enough knowledge yet to solve the *boss* exercises, learners are encouraged to fill these gaps, either by getting immediate feedback (enabled by *immediate feedback* principle) after failure (enabled by *freedom to fail* principle) and/or by skipping back to easier questions of the same *world* (enabled by *freedom of choice* principle). In this, the most challenging tasks are not only attended thanks to a raised motivation but also solved finally thanks to a raised understanding.

7 CONCLUSION & FUTURE PROSPECTS

In this work, four success factors to handle different competence levels in higher education mathematical e-learning are identified. Based on this factors, a frontend-oriented software approach for mathematical e-learning exercises is presented, that enables lightweight gamification implementation inside universities LMS. Four gamification design principles were derived, which led to an exercise design structured by *math worlds* and *boss* exercises, where learners get immediate feedback and are enabled to move along and repeat exercises without penalty. This exercise design was implemented with the help of the given frontend-oriented software architecture in the LMS Moodle.

In a first test run, we showed: (i) Students focus on solving the most challenging exercises (*boss* exercises). To achieve this, they repeat those exercises more often or jump back to previous questions, to acquire the needed knowledge. (ii) Students progress in their score performance by repeating exercises when being supplied with additional material (feedback). (iii) The perceived motivation of students towards present and future accomplishment of exercises lies above neutral, which indicates a raise in motivation. (iv) Students perceive the usage of game elements overall as suitable, but especially appreciate, that exercises appear in ascending difficulty.

In the future, this approach has to be tested in a test- and control-group research design, to give these findings more evidence. By additionally applying a math-skill pre-test, differences in effects regarding lower- and higher-skilled students can be measured. By this, more light is shed on how to facilitate a catch-up of lower-skilled students.

Thanks to its lightweight structure, this approach is not only extendable by the set of exercises, but also regarding the overall functionality. Using JavaScript, other gamification principles can be added easily to this basic implementation. Here, the presented approach offers possibilities to tackle a demand of recent gamification research (Behl et al., 2022; Zainuddin et al., 2020a): Elucidating the effects of single game elements (instead of overall gamification products). By adding or removing game elements with the help of JavaScript, specific outcomes (motivation, learning progress) can be mapped onto specific game elements (e. g. *storytelling*), regarding specific groups (e. g. lower- vs. higher-skilled students). In this, research regarding the question of how a catch-up of lower-skilled students regarding math with gamified e-learning exercises can be boosted.

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